

## **Geomorphology of Teton Canyon From the Confluence With Bitch Creek to the Confluence With Canyon Creek**

Note: This appendix provides a pool-by-pool description of the geomorphology of the Teton River canyon from the upstream extent of the former reservoir inundation area to five miles upstream of the Teton Dam site. This reach of the river was the most impacted from the landslides caused by the filling and subsequent drawdown of Teton Reservoir during the dam failure. Several cross section plots are referred to in the following text (surveyed in 1997-99) and can be located in Appendix E. Bathymetric maps that show the locations of cross sections, pools, rapids, and depths of each pool measured during field surveys are located in Appendix J. Travel times referenced in this section are discussed in the main report and presented in tables 12 and 13.

### **Bitch Creek**

The confluence of Bitch Creek and the Teton River marks the upstream extent of the former Teton Reservoir inundation just before the failure of Teton Dam. Between Bitch Creek and the first pool backed up by a landslide-formed rapid, the river is shallow and the channel bed is armored with 3-inch to 6-foot diameter boulders. It was observed during 1999 field work (discharge of 670 ft<sup>3</sup>/s) that the water depth in this reach was fairly uniform, approximately 2-4 feet in most places. A few shallow landslides are evident along the right canyon wall (looking downstream) in the downstream portion of this reach.

### **Pool 1**

Pool 1, formed by a rapid caused by the dam failure, is the upstream-most pool in the former reservoir inundation area. Five cross sections, approximately 100 to 150 feet in wetted width, were measured in Pool 1 during the 1999 survey. The channel bed in this pool is lined with gravels, cobbles, and patches of sand. A large eddy lined with sand exists in the left side of the pool just upstream of rapid 1.

Pool 1 is relatively short, approximately 260 feet in length which results in a short water retention time (on the order of a few minutes). Pools with short retention times tend to not trap the majority of fine sediments (clay, silt, and sand) transported by the river system. However, pool 1 would likely act as a trap for gravel and cobbles. Maximum channel depths measured at each cross section range between 10 and 18 feet. The fact that pool 1 still has significant depths after 20 + years since the dam failure suggest that the gravel and cobble load of the Teton River is small. In addition, the channel bed of the Teton River upstream of pool 1 consists primarily of boulders. This also indicates the gravel load of the Teton River is limited. It is likely that the dominant size of river bed-material transported by the Teton River is sand.

This pool inundated a predam rapid that can be seen in the 1972 aerial photographs. Several submerged tree stumps were evident along the left side of the pool (looking downstream) at depths of 1 to 2.5 feet. Prior to the filling of Teton Reservoir, all of the trees below the maximum reservoir inundation (elevation 5,300) were cut, but the stumps were left in growth position.

Because the trees require dry ground to grow on, areas where tree stumps are now submerged provide an indication of the predam terrace surfaces. In addition, tree stumps indicate the extent that the water surface elevation of the river has increased, and/or the wetted channel width of the river has expanded.

## **Rapid 1**

Rapid 1 is the upstream most rapid caused by the Teton Reservoir inundation. This rapid produces a 5-foot drop in water surface elevation. This rapid is a newly formed rapid originating from the left canyon wall during the Teton Dam failure. A separate rapid, slightly upstream of rapid 1, is evident in the 1972 aerial photographs. A debris chute that caused the formation of the rapid evident in the 1972 photographs can be seen in the 1997 aerial photographs. Although this rapid is now inundated by pool 1, the river channel constriction formed by landslide debris still persists. Just downstream of rapid 1, two cobble bars deflect the river flow. The water surface elevation through the cobble bars is fairly flat, with a small riffle just downstream causing an additional 2-foot drop in water surface elevation. This feature is not evident in the 1972 aerial photographs.

## **Pool 2**

This pool is approximately 1,360 feet in length and has a short retention time also, a few minutes longer than pool 1. Seven cross sections, approximately 150 feet in wetted width, were measured in this pool during the 1999 survey. Several tree stumps can be seen in this pool approximately 3.5 to 4.5 feet deep from the base of the stump to the water surface at the time of the 1999 survey (discharge of 670 ft<sup>3</sup>/s). There is a large amount of sand, gravel and cobbles along the channel bed in this pool. A relatively uniform water depth (average of 6 feet) was observed throughout the pool. This suggests that the pool has filled in to near capacity (for the given velocity and retention time of this pool) with sand since the dam failure in 1976.

## **Rapid 2**

Rapid 2 was a pre-existing riffle that was enlarged following the dam failure by landslides originating along both canyon walls, but primarily from landslide debris from the right canyon wall. This riffle constricts the river channel to a greater extent today (1997) than prior to the dam failure. Rapid 2 produces a 13.5-foot drop in water surface elevation.

## **Pool 3**

Pool 3 is approximately 2,390 feet in length and 10 cross sections were measured in this pool during the 1999 survey. This pool also has a short retention time, but is a few minutes longer than pool 2. In other words, the retention times increase in the downstream direction from pool 1 to pool 3 on the order of minutes. There are many variations in water depth throughout this pool. Shallow depths are inter-spaced with areas of significant water depths (up to 13 feet) with a

boulder and cobble-lined channel bed. However, where deeper portions of the pool exist, the width of the channel is much narrower (less than 50 feet as opposed to 100 feet in shallow areas) which results in higher velocities. As a result of the short retention time and high velocities throughout the pool, the pool is likely near capacity for storage of sand.

Cross sections 3-5 to 3-8 show some evidence of a terrace along river right that may now be inundated by 2 feet. At the downstream end of the pool in cross section 3-10, a terrace along river right is now inundated by 3 feet. These terraces may have been covered by landslide debris.

### **Rapid 3**

Rapid 3 was also a pre-existing riffle that was enlarged by landslides induced by the dam failure. One riffle at the upstream end of the present location of rapid 3, and another at the upstream end of pool 4 existed prior to the dam failure and the formation of rapid 3. Rapid 3 was created by a rock slide from the left side of the canyon and causes a 11-foot drop in water surface elevation.

### **Pool 4**

Pool 4, approximately 4,020 feet in length, is the longest of the nine pools in the Bitch Creek to Spring Hollow reach and has the longest retention time of over an hour. Fifteen cross sections were measured in this pool in the 1999 survey. At the upstream most end of the pool, the water depths range from 6 to 11 feet. A large landslide along the left canyon wall most likely contributed a large amount of debris to the channel bottom in the downstream 2/3 of this pool, resulting in the shallow depth areas and increased river stage. However, this landslide does not appear to have constricted the river channel. The maximum water depth in this pool of 15 feet is at a section near the center of the pool. The downstream half of this pool has a uniform channel bottom and water depth (average depth of 12 feet).

The majority of the pool has a sand-covered channel bottom. Rippled sand is evident in the downstream half of the pool which indicates small velocities. In addition, in the downstream half of pool 4, two debris chutes along the right canyon wall are evident in the 1972 aerial photographs. Debris from these chutes formed a constriction in the predam channel. Debris from these chutes appears to have been eroded out as the main channel was shifted to the right side due to the landslides along the left canyon wall. Terraces along river right are evident in the 1972 aerial photographs and are covered in places by landslide debris. Near the middle of pool 4 at cross sections 4-9 to 4-11, the top width seems to have increased significantly from 1972 conditions based on aerial photograph comparisons. The cross section plots show evidence that the river has inundated the terrace by up to 8-9 feet.

Three inundated tree stumps were observed in pool 4. At the upstream end of the pool near cross section 4-2 there is a tree stump along the right side submerged by 5.1 feet (from base of the stump to water surface at time of survey). The second tree stump, submerged by 2.7 feet, is along the left bank approximately 200 feet upstream from cross section 4-3. The third tree stump is very large, and is submerged to a depth of 6.7 feet at the downstream end of pool 4 along the left side just upstream of rapid 4.

## **Rapid 4**

Rapid 4 is a previously existing rapid that was enlarged by extensive landslides caused by Teton Reservoir along the left canyon wall. The former riffle originated from a debris chute along the right canyon wall and caused a small constriction in the river channel. This rapid causes a drop in water surface elevation of 16 feet, but occurs over an extended distance of 1700 feet.

## **Pool 5**

Pool 5 is approximately 2,780 feet in length. Fourteen cross sections were measured in this pool in 1999. The retention time in pool 5 is over an hour, a few minutes shorter than pool 4. Maximum measured channel depths at each cross section in pool 5 are significant (majority range from 11 to 19 feet). It was difficult to observe the channel bottom during the 1999 survey. The majority of sediment appeared to be silt and clay with a few boulders, most likely derived from local landslide sources. The sediment distribution in pool 5 suggests that the majority of sand transported by the river is being trapped upstream of rapid 4. On the basis of sediments observed along the channel bed, measured pool depths and channel widths, and computed water travel times, pools 1-3 appear to be near the maximum storage capacity for sand, while pool 4 is in the process of reaching this stage.

At the downstream end of pool 5 at cross section 5-10 and again at 5-14, a narrow terrace is inundated along the left side of the river by 10-12 feet. At cross sections 5-6 to 5-8, a terrace is again evident along the left side of the river and has been inundated by 4-6 feet. At cross section 5-4, a terrace along the left bank is inundated 2 feet.

## **Rapid 5**

Rapid 5 is a newly created rapid caused by the dam failure. Rapid 5 causes a drop in water surface elevation of 8.5 feet. This rapid was formed by debris from a landslide along the left canyon wall. A few boulders are evident in the location of rapid 5 in the 1972 aerial photographs. While a rapid is not evident in the 1972 aerial photographs at this location, the constricted river channel width is similar to existing conditions.

## **Pool 6**

Pool 6 is divided into two pools by a short rapid (rapid 6), followed by a small riffle (riffle 6). The first pool, 6A, is the main part of the pool and is approximately 1,870 feet long. Pool 6B is a very short section, less than 100 feet long. There were nine cross sections measured in pool 6A, and 2 cross sections measured in pool 6B during the 1999 survey. Maximum channel depths at each cross section are again significant in pool 6A, ranging between 13 and 20 feet. Maximum channel depths measured in pool 6B are less than 5 feet. The retention time in pool 6A is near 50 minutes, while in pool 6B it is only a few minutes.

There are several eddies in pool 6A that are filled with silt, clay, and large amounts of aquatic vegetation. In the 1972 aerial photographs, a vegetated island is evident just upstream of the current location of rapid 7. There may be evidence of this vegetated island in cross section 6-9. A terrace is evident along the left side of cross section 6-5 that is inundated approximately 9 feet. Another terrace is evident along the right side of the river in cross section 6-7 that is inundated 8 feet.

## **Rapid 6 and Riffle 6**

Rapid 6 is a newly formed rapid caused by the Teton Dam failure that results in a 6-foot drop in water surface elevation. Riffle 6 causes an additional 3-foot drop in water surface elevation. Rapid 6 was formed from landslide debris originating from the left canyon wall, and riffle 6 debris originated from the right canyon wall.

## **Pool 7**

Pool 7 is approximately 700 feet long. Five cross sections were measured in this pool during the 1999 survey. Maximum measured channel depths at each cross section average 8 feet in the upstream half and 4 feet in the downstream half of the pool. The retention time in pool 7, and in pools 8 and 9, is only a few minutes. During the dam failure, several landslides occurred along the right and left canyon walls in this reach that contributed sediment to the river. There were no rapids or riffles evident in this reach in the 1972 aerial photographs.

## **Rapid 7**

Rapid 7 is a newly created rapid caused by the dam failure that causes a drop in water surface elevation of 4 feet. The rapid was formed from landslide debris originating from both canyon walls.

## **Pool 8**

Pool 8 is relatively short, approximately 520 feet long. The two cross sections measured in this pool during the 1999 survey have a wetted width of 150 feet. The average maximum measured

channel depth is 8 feet. At the downstream end of pool 8, a longitudinal island is evident in the 1972 aerial photographs. The material from this island is still visible today just upstream of rapid 8. Large boulders were observed along the left side of the river at cross section 8-2.

## **Rapid 8**

Rapid 8 is a newly formed rapid caused by landslides induced along both canyon walls by the dam failure, but primarily from the left. This rapid causes a drop in water surface of 2.5 feet. In the 1972 aerial photographs, an island just upstream of this rapid appears to have created a small riffle in the river channel.

## **Pool 9**

Pool 9 is approximately 520 feet long. Three cross sections were measured in pool 9 during the 1999 survey that have a wetted width of 150 feet. The maximum measured channel depth is 11 feet in the upstream half of the pool and 8.5 feet in the downstream half of the pool. There are several landslides along the left canyon wall in this pool that have contributed sediment to the river channel. A tree stump that was inundated approximately 1 foot was observed along the left side of the channel between cross sections 9-1 and 9-2.

## **Rapid 9 at Spring Hollow**

Landslides resulting from the filling and subsequent failure of Teton Dam are evident on the left canyon wall at the mouth of Spring Hollow (photograph A-11). Evidence in older photography indicates that the landslide resulting from the 1976 failure occurred at a location in the canyon that had been the site of previous landslides. Prior to the dam, there was a mid-channel bar formed by alluvium from Spring Hollow and the main channel of the Teton River flowed along the left side of the canyon. Landslides on the left side of the canyon blocked this channel and coarse debris from the slide created a rapid immediately upstream of Spring Hollow (rapid 9). However, the channel configuration at the mouth of Spring Hollow prior to the dam had been largely controlled by the sediment delta related to the tributary drainage.

## **Pool 10**

Pool 10 is located immediately downstream of Spring Hollow. Three cross-sections were measured in the pool in July 1998. The pool is approximately 770 feet long. Cross-section 10-1 is located just downstream from the longitudinal island at Spring Hollow. The bed and banks in this part of pool 10 appear to have been elevated by relatively finer-grained debris transported downstream from the slide upstream of Spring Hollow that forms rapid 9. Cross-section 10-2 is located in the middle of pool 10. The left portion of this cross section (both channel bed and bank) also appears to be elevated from predam conditions by finer-grained

material originating from the slide debris. Cross-section 10-3 is located at the downstream end of pool 10. The entire cross section is similarly elevated, but by landslide debris from the right side of the canyon that forms rapid 10.

An extensive low terrace was present along the right bank between cross-sections 10-2 and 10-3 before the inundation by the reservoir. The terrace was subsequently eroded due to the change in the channel configuration upstream and inundated by 3 to 4 feet in the pool backed up by rapid 10 and the addition of landslide debris to the channel.

### **Rapid 10 (Riffle)**

Rapid 10 actually consists of two small riffles with a total drop across the pair of at least 1.5 feet. Both riffles are formed primarily of debris from a shallow landslide on the right side of the canyon. No constriction or rapid was present at this location prior to the inundation by the reservoir.

### **Pool 11**

Four cross-sections were measured in pool 11 in July 1998, cross sections 11-1, 11-2, 11-3, and 11-4. The pool is approximately 2,010 feet long. Prior to inundation by the reservoir, the reach of the river now in the upstream part of pool 11 contained numerous large boulders that appear to have come from rock falls on the right canyon wall. Numerous old landslide scars in this reach are also evident in older aerial photography. In addition, a large island at approximately the present location of rapid 11 deflected the river channel toward the right side of the canyon. A narrow terrace was present along the entire right side of the river through pool 11 to the island. The boulders, island, and low terraces are now shallowly submerged.

The cross section surveys show two predam terraces now submerged in pool 11. The older of these terraces is now submerged to a depth of 5 feet. The younger terrace, visible in the older aerial photography, is now submerged to a depth of 2.5 feet. The presence of an older submerged terrace suggests that an earlier landslide, perhaps the remnant of which forms the mid-channel island in the older photography, caused an increase in pool depth prior to the dam failure. Cross-section 11-3 may provide evidence of old landslide debris (pre-1976) in the left half the section. On the basis of the cross-section surveys, the channel bottom through this reach was not significantly affected by landslide debris or redistribution of landslide debris, as was pool 10.

### **Rapid 11**

Rapid 11 was formed by landslides from both sides of the canyon and creates a 5-foot drop (photograph A-37). The older aerial photography shows an old landslide scar on the right side of the canyon at this location and a few very large boulders constricting the channel and creating a riffle.

## **Pool 12**

Seven cross-sections were measured in pool 12. The pool is approximately 1,940 feet long. On the basis of a submerged terrace along the left side of the channel, the pool elevation has increased by 2.5 feet. This terrace is evident in cross-section 12-1, and a submerged mid-channel bar is evident in cross-section 12-6 and possibly 12-5. The older aerial photography shows a low terrace on the left side of the channel with a backwater channel. Most of the terrace is above the water surface and covered with vegetation. A mid-channel bar is evident in the older aerial photography near the location of cross-section 12-6 which is now inundated by about 2.5 feet. The mid-channel bar can still be seen as a submerged bar in the 1997 photos. However, there is now an additional transverse bar superimposed on the mid-channel bar (photograph A-36). The source of sediment for this new transverse bar is the landslides originating from the left side of the channel. It appears that landslide debris blocks the channel on the left side of the canyon and buried the downstream end of the mid-channel bar. The older aerial photography also shows evidence of a wide terrace on the right side of the river in the downstream half of pool 12. In the 1997 aerial photographs, the downstream end of this terrace appears to be buried by landslide debris from the left side of the canyon.

Cross-sections measured in pool 12 and 1997 aerial photographs show no evidence of significant deposition along the channel bottom as the result of the 1976 landslides. However, the left side of the channel between cross-sections 12-5 and 12-6 was apparently blocked by landslide debris. Erosion of that debris has partially reformed the channel.

## **Rapid 12**

Drop in the water surface through rapid 12 was measured at about 3 feet. The source for this rapid appears to be from 1976 landslides on the left side of the canyon (photograph A-35). In the 1972 aerial photographs, a few boulders are evident above the water surface at this location along both edges of the channel, creating a riffle, but no large rapid exists. The 1997 aerial photos show that the present channel has a constricted width through the rapid relative to the channel width in 1972. An overflow channel (accessed only by high flows) has developed along the right edge of the canyon wall.

## **Pool 13**

Pool 13 is approximately 1,100 feet long. There is a long, narrow terrace in the upstream portion of the pool on the right side. Neither of the measured cross-sections (13-1 and 13-2) show evidence of this terrace. The 1997 aerial photos show a 1976 landslide may have deposited material directly on this right terrace. This may be due to their location within the pool (i.e., XS 13-1 is at a diagonal and may not reach the right bank). Cross-section 13-1 appears to have landslide debris originating from a 1976 landslide on the right side. Cross-section 13-2 is located at the top of the rapid.



## **Rapid 13**

The total drop through rapid 13 is about 5 feet. Rapid 13 is formed by two slides from the left canyon wall and material from an ancient slide that was re-mobilized. Prior to the dam, there is a mid-channel bar at the present location of the middle of rapid 13. Scattered boulders appear above the water surface along the edge of the channel forming a riffle, but no rapid is observed. These boulders appear to have originated from rock falls on the right side prior to 1972. To recreate predam (1972) conditions for hydraulic modeling, rapid 13 cross-sections could be widened.

## **Pool 14**

Pool 14 is approximately 1,700 feet long. There appears to be relatively little change in the channel through this reach due to the 1976 landslides. There are several shallow slides at the downstream end near rapid 14. One of these slides forms a mid-channel bar. Cross-section 14-1 shows evidence of a submerged terrace at a depth of 3-4 feet. This terrace can be seen along the right bank in the 1972 aerial photographs near the upper end of pool 14. The 1972 aerial photographs show a submerged mid-channel bar at the approximate location of cross-section 14-1. This feature is observed in the 1997 survey at cross-section 14-1.

## **Rapid 14**

There is presently a drop at this location about 3.5 feet through this rapid. Prior to inundation by the reservoir, there is no evidence of a rapid. The rapid appears to have been formed from 1976 landslide deposition from both the right and left sides of the canyon, although, most of the debris forming the rapid came from the right side of the canyon.

## **Pool 15**

Pool 15 is approximately 1,480 feet long. Prior to the dam a narrow terrace was present along the right bank of the pool. This terrace had a few trees and lots of low vegetation. The construction of Linderman Dam formed a pool, which submerged this terrace. In the 1972 aerial photos, Linderman Dam was backing up water near the upstream end of pool 15. The 1997 aerial photos show evidence that this terrace is still submerged, but due to the 1976 landslides instead of Linderman Dam (the remainder of this dam no longer acts as a hydraulic control upstream of rapid 16). During the 1998 field survey, it was noted that the base of a juniper tree at the upstream-most end along the right bank of pool 15 was submerged to a depth of approximately 3-5 feet (photograph A-34). Note that the juniper tree was growing just upstream of the pool formed by Linderman Dam.

Cross-section 15-1, located at the top of pool 15, was not surveyed across the right half of the channel and cannot be used to verify the existence of a submerged terrace. However, cross-sections 15-2 and 15-3 both show evidence of the submerged terrace on the right side. From this data, this terrace is submerged 3-4 feet, which is consistent with the aerial photographs. None of

these sections appear to have been affected by 1976 landslide debris, although the pool is deeper than before the 1976 landslides. The 1972 reservoir basin topographic map shows the approximate elevation of what is now pool 15 to be about 5156 feet. The current average elevation of pool 15, based on survey data, is about 5159 feet. This is a 3-foot increase over the predam conditions. This 3-foot increase agrees with observations made in July 1998, of a juniper tree rooted on a low terrace are submerged to a depth of about 3 feet (photograph A-33).

## **Rapid 15**

Rapid 15 is made up of two rapids formed by a large slide from the left canyon (SE) wall. Rapid 15 is fairly long, about 3-4 channel widths in length with a measured 6.0 feet of drop across the entire rapid. There is no evidence of a rapid in the 1972 aerial photographs. There is an overflow channel forming at the upper left side of the rapid. Boulders in slide debris exhibit thick calcium carbonate coats indicating that debris forming the rapid was stable for tens of thousands of years prior to failure.

## **Pool 16**

Pool 16 is approximately 680 feet long. The 1972 aerial photographs show a low terrace along the right bank. This terrace is an extension of the terrace evident in pool 15. The terrace is supporting trees along the right bank in 1972. This terrace is in the 1997 aerial photos. The 1997 cross-section data shows evidence of a submerged terrace on the left bank in cross-section 16-1. There is also a break in channel slope evident on the depth charts in cross-section 16-2 and 16-3. Along the right bank, small shallow slides from 1976 are evident but none of these cross-sections appear to have been affected by 1976 landslide debris. Measurements of the water depth over the inundated terrace indicate that the pool depth is elevated by approximately 3 feet.

## **Rapid 16**

The drop through this rapid is about 2.5 feet. There is no evidence of this rapid in the 1972 aerial photographs. The source for this rapid is from a series of relatively shallow landslides on the left side of the canyon. This rapid has substantially constricted the channel. The water surface elevation in the pool upstream of Linderman Dam (in 1972) was estimated to be about 5155 feet. The water surface elevation of pool 16 was measured in 1997 to be an average of 5153 feet. This means the pool elevation today is approximately 2 feet lower than it was in 1972. Therefore, Linderman Dam served as a greater hydraulic control in 1972 than the combined effect of what is left of Linderman Dam and rapid 16.

## **Pool 17**

Pool 17 is formed behind the remnants of Linderman Dam and an alluvial fan delta from Milk Creek and forms the left abutment of Linderman Dam, which runs into Teton River in the vicinity of Linderman Dam. Pool 17 is approximately 790 feet long. The delta formed by Milk Creek (shown as submerged in the 1972 aerial photographs) is substantially exposed in the 1997 aerial photographs. Portions of the delta downstream of Linderman Dam are now submerged in the 1997 photos. There are no apparent landslides from 1976 along either bank of this pool. Cross-section 17-1, just upstream of the dam, shows some evidence of the submerged portion of the delta.

## **Pool 18**

This is a short pool, about 520 feet long, directly downstream of Linderman Dam. The 1972 aerial photos show an alluvial fan and delta on the left side of the channel by Milk Creek. This alluvial fan and delta have been highly modified by the construction activities for Linderman Dam. The left bank in the present location of pool 18 appears to have been excavated creating a broad low bench at or near the 1972 water surface elevation. In the 1997 aerial photos this bench is inundated by as much as 4 feet. Cross-section 18-1, just downstream of the dam at the top of the pool, shows a deep scour hole on the right side about 27.5 feet deep. The location of this hole is consistent with the location of the outlet/spillway of Linderman Dam and the position of the pre-Linderman Dam channel. There is also a terrace on the left side inundated by about 8 feet. This terrace may have been created by excavation during the construction of Linderman Dam. Cross-section 18-2 also shows a broad terrace inundated by about 4 feet on the left side. The deep portion of this cross-section reaches a depth of about 16 feet. The alluvial fan delta formed at the mouth of Milk Creek has deflected the course of the Teton River to the right side of the canyon. Rock straths preserved about 28 feet above the present water surface elevation provide evidence that the location of the Teton River channel in this reach has been largely controlled by deposition from Milk Creek. The water surface elevation in pool 18 is estimated to have increased about 4 feet above predam conditions. This is confirmed by the data in cross-section 18-2 and the hydraulic drop through Linderman Dam.

## **Rapid 18**

The measured drop through this rapid is about 6.0 feet. There is no evidence of a rapid of this size in the predam aerial photography, but there is a minor riffle evident at the current location of the rapid indicating a shallow channel depth. This riffle is probably the result of an older landslide on the left bank at the upstream end of the present rapid. A slide at the same location was triggered by the 1976 landslide and destabilized material that was at least late Pleistocene in age. The 1976 landslide was orders of magnitude larger in terms of volume and deposited debris into the river creating a rapid and severely constricted the channel. The debris has constricted the channel by at least half the channel width.

## **Pool 19/20**

Pools 19 and 20 are separated only by a shallow set of riffles. Pool 19 is approximately 2,000 feet long and pool 20 is approximately 450 feet long. A narrow terrace on the right side of the river downstream of the present location of rapid 18 has been completely eroded. This erosion was likely caused by the redirection of flow in the main channel as a result of the landslide and increased flow velocity due to the channel constriction caused by the rapid. Survey data were collected in 1997 in both pools. A low terrace is evident along the left and right side of the present pools. Also, several large boulders are evident in the middle of the channel resulting from rock falls on the right side of the canyon. The river channel through pools 19 and 20 prior to the 1976 failure of Teton Dam was characterized by a channel of uniform width. No major rapids or riffles were present through the reach. However, the channel was punctuated by small mid-channel bars that had formed downstream of large boulders, the product of rock falls from the right canyon walls. In addition, prior to inundation by the reservoir, a low terrace was present along both sides of the channel. The 1997 aerial photos show evidence that the terrace on the right side has been eroded and the material transported downstream. The landslide on the left side of the canyon that formed rapid 18 deflected the channel to the right side of the canyon and caused erosion of this terrace.

Cross-section 19-1 is a relatively wide section with a channel width of 300 feet and is located at the upstream end of pool 19. This cross-section shows a submerged mid-channel bar that is evident in both the 1972 and 1997 aerial photos. Cross-sections 19-2 and 19-3 are about half the channel width of cross-section 19-1. Cross-section 19-4 is located just upstream of the start of the riffles and is about 200 feet wide. Cross-section 20-1 is located in the short pool between the end of the riffles and the beginning of the rapid.

## **Rapid 19/20 (Riffles)**

These rapids were created by a very large landslide on the left canyon wall and formed a set of four constrictions with a small pool separating the first three riffles from the fourth. The combined drop through the first three riffles is about 7.0 feet (rapid 19). The drop through the last, and biggest rapid in the series is about 4.5 feet (rapid 20). Evidence in the 1972 photos indicates that these islands are formed of rock debris from the right canyon wall. However, the channel is not constricted other than the mid-channel bar splitting stream flow. The 1997 aerial photos show large constrictions for each of the 4 rapids in the series. All of the rapids formed as the result of the 1976 landslides along the left bank.

## **Pool 21**

Pool 21 extends through a straight reach of the canyon, which is oriented in an NE-SW direction, for approximately 1,800 feet. No landslide scars were observed along either side of the canyon in the 1957 or 1972 aerial photos. The only landslides in this reach of the river that resulted from the 1976 dam failure are those forming rapids 20 and 21. Prior to the dam failure, long narrow terraces were present on both sides of the river through pool 11. In

addition, numerous mid-channel bars and large boulders were present. In the 1997 aerial photographs, the terraces have been inundated by the pool water surface ponding behind rapid 21.

Four cross-sections were surveyed across this pool. Cross-section 21-1, located at the top of the pool, shows no evidence of submerged terraces or coarse landslide debris. Cross-section 21-2, in the upstream portion of pool 21, shows a submerged bar in the center of the channel at the approximate location of the shallow bar evident in the 1972 aerial photos. Data from cross-section 21-3 suggest that the submerged terrace is inundated to a depth of about 1 foot. The channel bottom along cross-section 21-4 (from the depth chart) is very flat. On the basis of the measured cross-section data, it appears that the terraces are submerged by a minimum depth of 1-2 feet.

## **Rapid 21**

The measured drop through this rapid is 3 feet. The 1972 aerial photos show a large talus slope on the right bank which was the source of a few boulders in the channel just upstream of the current location of the rapid. However, there was no rapid at this location before the dam failure. Landslides on both the right and left sides of the canyon caused a rapid to form and the river channel to be constricted. Debris forming the landslide from the left side of the canyon is comprised in large part of re-mobilized alluvial fan sediment at the mouth of a small tributary herein referred to as County Line Creek. The alluvial fan at this location prior to the failure deflected the river channel to the right side of the canyon.

## **Pool 22**

Pool 22 is very short at a length of approximately 730 feet. The 1972 aerial photographs show a narrow terrace on both sides of the pool. No pre-1976 landslide scars are evident. In this reach, however, numerous boulders in the channel and mid-channel bars are present in the 1972 aerial photographs.

Two cross-sections were measured in pool 22. Cross-section 22-1 is relatively narrow (150 feet) while cross-section 22-2 is much wider (300 feet). The bottom of cross-section 22-2, which is just upstream of rapid 22, is very rough most likely reflecting coarse landslide debris in the channel.

## **Rapid 22**

Rapid 22 was formed by a very large landslide from the left canyon wall (photograph A-30). Stream flow is currently split around a mid-channel island formed of landslide debris and a previously existing mid-channel bar. The rapid is located on the right side of the island. Landslide debris blocked the left side of the channel and buried the existing mid-channel bar. The measured drop through this rapid is about 3.0 feet. Three mid-channel bars in the current location of rapid 22 existed in the channel prior to the 1976 failure. The two islands located where the current rapid is were longitudinal - one about one channel width long. These islands probably formed as

bars on the downstream side of boulders that fell into the channel from the adjacent canyon walls. This idea is supported by the presence of other large boulders in the channel on the 1972 aerial photographs.

### **Pool 23**

Pool 23 is approximately 1,500 feet long (photograph A-29). Through the pool, there are numerous landslides on the left side of the canyon with a debris island located about 1/3 the length of the pool from rapid 23. With the exception of a small rock fall located on the right side about midway through the pool, there are no significant landslides on the right side of the canyon. Low, narrow terraces were present along both banks of the channel at the present location of the pool.

Numerous cross-sections were measured through pool 23. The thalweg portion of cross-section 23-1 is 9 feet deep and narrow (about 25 feet). This narrow deep portion may be the result of scour downstream from rapid 22. Cross section 23-2, located just upstream from the debris island, is relatively shallow (maximum depth of 5 feet) and the bottom is very rough. This is undoubtedly due to the existence of mid-channel bars in the area prior to the dam failure, landslide debris, and possibly material eroded by scour downstream of rapid 22. Cross sections 23-3 and 23-4 are both relatively deep (10 to 11 feet) and smooth. None of the cross sections show evidence of submerged terraces, except for cross section 23-1 which shows a narrow terrace along the right bank submerged to a depth of 1 foot.

### **Rapid 23 (Chute of Riffles)**

Rapid 23 is a long (approximately 1,400 feet), narrow section of channel comprising a major rapid with 3.5 feet of drop and a series of riffles just downstream of the major rapid that account for an additional 10 feet of drop. The series of riffles end just downstream of a tributary stream and alluvial fan, herein referred to as Wheat Creek (after survey control "Wheat" which is located on the Canyon rim). The gradient through this reach does not appear to have significantly changed as a result of the 1976 landslides. At the downstream end of the rapid, there is a triangular shaped island. There are no landslides on either side of the canyon at the location. It appears that the island formed from sediment transported into the reach from the landslides upstream.

### **Pool 24**

This pool begins just downstream of the long series of riffles (downstream of pool 23) that are approximately 2,100 feet long. Pool 24 is approximately 2,850 feet long. There is a small mid-channel bar at the upstream end of the pool. This mid-channel bar apparently formed as a result of re-mobilized landslide debris upstream and on the adjacent canyon walls. The pool makes a sharp bend (100 degrees) to the right. A large point-bar terrace is present along the right canyon wall. This is the largest terrace along the river between this location and Spring Hollow. On the basis of its elevation above the present channel, and observations of particular soil properties exposed along the river, the terrace is interpreted to be early Holocene to late Pleistocene in age (<14,000 years old). The surface morphology of the terrace is basically unchanged relative to the

pre-1976 failure configuration with the exception of the vegetative cover. Prior to the dam failure, a narrow, terrace inset below the older terrace existed along the right bank. In addition, two debris fans on the left side of the canyon opposite the terrace constricted the river in three places and produced a series of riffles through this reach. These riffles do not exist at this location currently, in part because of an increase in the pool elevation behind rapid 24.

Five cross-sections were measured in this pool. Cross section 24-1, at the upstream end of the pool indicates that the channel is relatively shallow with a maximum depth of 4 feet. The bottom of cross section 24-2 is also relatively shallow, particularly along the left side of the channel where it is only 1.2 feet deep. This reach of the channel is interpreted to be an eddy bar formed from redistributed landslide debris apparently transported by the river from landslide sources upstream. Cross sections 24-4, 24-5, and 24-6 do not show any noteworthy features. A point bar just upstream of rapid 24 extending upstream into pool 24 remains relatively unchanged as a result of inundation by the reservoir.

## **Rapid 24**

Rapid 24 is formed by a large landslide from the left canyon wall just downstream of an early Holocene or late Pleistocene terrace. The measured drop through the rapid is 3.5 feet. A small riffle appears to have existed at this location prior to the 1976 dam failure. The change in water surface elevation in pool 24 due to this rapid was enough to inundate the toe of the debris chutes evident in the 1972 aerial photography.

## **Pool 25**

Pool 25 is the longest pool (5,220 feet) in the reach of the river between Spring Hollow and Canyon Creek. Through the entire length of the pool, the left canyon wall is marked by extensive landsliding. With the exception of one large slide approximately midway in the pool, none of the slides appear to seriously impact the channel other than moving easily eroded sediment to a position adjacent to the river. Through the length of the pool, the river rounds three bends. All three of these bends have either a low terrace or point bar on the inside of the bend. There are also low, narrow terraces along the straight reaches between bends on both banks. In the lower reach of pool 25, the canyon walls are marked by ancient landslide scars. There is evidence of a large landslide scar at the present location of the rapid in the 1957 and 1972 aerial photographs. Several debris fans also existed on the left side of the canyon between the second bend and third bend, numerous riffles are evident in the 1972 aerial photos through the length of pool 25.

Results of the 1997 and 1998 field surveys show evidence of all of the previously existing (pre-1976) terraces and bars are partially inundated. Cross-section 25-1, which is located at approximately the center of the first bend, shows evidence of a new eddy bar along the left bank. This bar was formed by redistribution of landslide debris transported from upstream. Cross-section 25-3, shows a submerged terrace along the inside bend (left side) at a depth of 1-2 feet and a submerged bar or terrace along the inside bend (left side) at a depth of 4-5 feet. Cross-section 25-4, located near the downstream end of the first bend, shows a submerged terrace on both sides of the channel with a break in slope at about 3.5 feet. There are landslides evident

along the left side of the downstream portion of this first bend. A small amount of debris from these landslides reached the left side of the channel, but at present do not significantly impact the river channel.

Cross-section 25-5, located in the upstream portion of the second bend, also shows an inundated terrace on the inside bend (right bank) at a depth of approximately 3.5 feet. The left bank terrace is buried by slide debris. Cross-section 25-6, located just downstream from the middle of the second bend, crosses a point bar on the inside bend (right bank) inundated by a depth of 3.2 feet. There are no significant landslides along either canyon wall through the second bend. With the exception of the larger slide near cross-section 25-5, the slides that were mapped on the 1976 landslide maps along the left canyon wall had minimal impact on the channel.

Cross-section 25-7 is located between the second and third bends. The channel bed of this cross-section does not appear to be affected by the 1976 landslide debris. Similarly, cross-section 25-8 is relatively unaffected by landslide debris and is rectangular in shape with a maximum depth of 12.8 feet. Cross-section 25-9, just upstream from rapid 25, is a shallow cross-section with a maximum depth of 7 feet and a very rough bottom. This suggests that landslide debris occurs on the channel bed. This is supported by geomorphic evidence indication that the large landslide on the left canyon wall now forming rapid 25 crossed and completely blocked the channel.

## **Rapid 25**

Rapid 25 is formed by a large landslide from the left canyon wall. The measured drop through this rapid is about 3.0 feet (photograph A-28). There is evidence of several riffles in the reach downstream of rapid 25 in the 1972 aerial photos. Rapid 25 occurs at the same location as a very extensive ancient landslide. Several older landslide scars are apparent in the 1957 and 1972 aerial photographs. The riffles present at this location prior to the inundation by the reservoir may in part represent the remnants of older landslide debris.

## **Pool 26**

Pool 26 is approximately 2,360 feet long and consists of 2 straight sections joined by about a 45-degree bend to the left. Around the bend a vertical rock wall exists on the left and a narrow vegetated terrace is evident on the right. The 1972 aerial photos show a large landslide scar on the left side of the canyon just upstream of rapid 26. The landslide created a large debris fan that deflected the channel. A narrow terrace along the left bank widens across the toe of the debris fan. A terrace along the right side of the channel was also evident through the reach, but narrows at the debris fan. In the 1997 aerial photographs, a new landslide is evident immediately upstream of the old landslide scar which constricts the channel. There are also several minor slides along the right side of the canyon, but they appear to have little impact on the channel. A submerged bar is present along the right side of the channel from rapid 25 through the bend. Another submerged terrace is evident on the left side downstream of the bend and upstream of the new landslide. Several additional submerged bars can be seen in the downstream end of this pool near rapid 26. The 1997/1998 survey shows the increased water surface elevation has generally increased top widths throughout the pool except at the constriction of the new landslide.



Cross-section 26-1 is located in the upstream portion of the pool and is relatively narrow with a width of 125 feet. The left side of the cross-section is very steep. Cross-section 26-1 shows submerged terraces are evident on the right side to a depth of 3 and 10 feet. Cross-section 26-1 has a maximum depth of 16.5 feet. Cross-section 26-2 is slightly skewed in the downstream direction which accounts for a much wider top width of more than 300 feet and has a maximum depth of 17.3 feet. Cross-section 26-2 shows a submerged terrace on the right of approximately 3 feet in depth. Cross-section 26-3 shows a relatively smooth channel bed, is relatively narrow with a top width of 175 feet, and a maximum depth of almost 19 feet. No terrace is evident on either side of the cross-section. Cross-section 26-4 is a relatively narrow V-shaped section with a width less than 150 feet and shallow with a maximum depth of 8.5 feet. This cross-section was likely filled in with coarse debris from the 1976 landslide on the left side of the canyon. Cross-sections 26-5 and 26-6 are near rapid 26, are shallow and very rough. This indicates presence of coarse landslide debris on the channel bottom. The maximum depth in cross-section 26-5 is about 9.6 feet and in cross-section 26-6 is about 6 feet.

## **Rapid 26**

This rapid has a measured drop of about 3.5 feet that only constricts the channel a small amount (photograph A-27). The 1997 aerial photos show evidence that this rapid was formed from a 1976 landslide on the right side with small amounts of material from the left side. The 1972 aerial photos show no evidence of a rapid at the same location, but do show a large longitudinal island just downstream.

## **Pool 27**

This pool is very short (500 feet) and is fairly wide (250 feet) (photograph A-25). There are no landslides evident in the 1997 aerial photos between rapids 26 and 27. In the 1972 aerial photos there is a terrace along the right side of the pool and a vegetated island in the middle of the pool. There is also a bar - half of which is submerged that extends from the right bank diagonally to the downstream end of the island. The island combined with the bar makes a V-shape feature in the channel. In 1997 the island and bar are completely gone. Cross-sections 27-1 and 27-2 show the current pool to be about 13 feet deep.

## **Rapid 27**

In the Spring Hollow to Canyon Creek reach, this rapid has the largest measured drop of over 16 feet (photograph A-21). This rapid is not evident in the 1972 aerial photos, although a long riffle is present through the reach now under pools 26 and 27. The rapid was formed by several large landslides on the left bank (photograph A-22, A-24). Downstream of the rapid, several constrictions and islands are evident in both the 1972 and 1997 photos - although they are in different shapes and positions. The islands are mapped on the landslide maps as being composed in part as landslide debris, but it is apparent from pre-dam photography that these islands existed prior to the inundation of the canyon by the reservoir. It is possible that at the time the landslide mapping was being undertaken, that debris from upstream landslides was being transported downstream where it was deposited on existing bars.